WRP Technical Note HY-IA-3.1
August 1993

Installing Monitoring Wells/ Piezometers in Wetlands

PURPOSE: Wetland regulatory personnel frequently need quantitative information about shallow hydrologic regimes of wetlands and adjacent uplands. Monitoring wells and piezometers are some of the easiest instruments to use to determine depth of shallow water tables. Most of the literature on piezometers and monitoring wells, however, deals with installation to greater depths than needed for wetland regulatory purposes. This technical note describes methods of construction and installation of monitoring wells and piezometers placed at depths within and immediately below the soil profile using hand-held equipment.*

DIFFERENCE BETWEEN SHALLOW MONITORING WELLS AND PIEZOMETERS: Monitoring wells and piezometers are open pipes set in the ground. They passively allow water levels to rise and fall inside them. The difference between a monitoring well and a piezometer is where along the pipe water is allowed to enter (length of perforated area).

Shallow monitoring wells allow penetration of water through perforations along most of the length of the pipe below ground. Therefore, the water level in a monitoring well reflects the composite water pressure integrated over the long, perforated portion of the pipe. This kind of well sometimes is called an "open-sided well," "observation well," or a "perforated pipe."

Piezometers allow penetration of water only at the bottom of the pipe, either directly into the bottom or along a short length of perforation near the bottom. Consequently, the water level in a piezometer reflects the water pressure only at the bottom of the pipe. Piezometers are sometimes called "cased wells."

The difference between monitoring wells and piezometers is significant because monitoring wells generally extend through more than one water bearing layer and therefore cannot be used to detect perched water tables, whereas piezometers can. Water pressures in the soil vary in response to several factors, including depth, differential permeability of strata, and water flow. These different factors can be isolated and interpreted independently with groups of piezometers. These factors cannot be differentiated with a monitoring well because different water pressures are intercepted at many depths within the same instrument and cannot be sorted out.

SELECTING INSTRUMENTATION: Before installing instruments, it is vital to define study objectives to avoid gathering unnecessary or meaningless data.

To investigate when a free water surface is within the top foot or two of the soil, 2-ft deep monitoring wells are sufficient. Deeper instruments are not necessary and may yield misleading information if improperly chosen and situated.

* The methods described herein do not apply to water-sampling studies. Researchers needing to sample water from wells should refer to U.S. Army Corps of Engineers Document EM 1110-7-1(FR): Monitor Well Installation at Hazardous and Toxic Waste Sites and ASTM D5092-90: Design and Installation of Ground Water Monitoring Wells in Aquifers.

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When trying to characterize water flows into and out of a wetland or differences in water pressure of soil horizons, clusters or "nests" of piezometers are needed. Most mitigation and evaluation studies require nests of piezometers with instruments located at depths ranging from a couple to many feet. Each piezometer in a nest should be installed at the same surface elevation and within a couple meters of the others. This arrangement allows answering questions about ground-water discharge and recharge, direction and rate of water flow, and water flow in different strata.

Zones of possible perching or water flow must be identified after study objectives are determined. This requires soil profile descriptions to the depth of interest -- often 6 to 10 ft. The profile descriptions should include horizon depths and information from which significant differences in permeability can be inferred: texture, induration, and bulk density.

If only shallow monitoring wells are used, they should be placed above the first slowly permeable horizon that could potentially perch water. Piezometers, on the other hand, should be installed both above and below horizons of low permeability to verify perching. Sand strata should also be monitored. Instruments should not be located at uniform depths around a study area unless the soils are uniformly stratified.

Typical well configurations include a shallow monitoring well through the A and E soil horizons and piezometers in the B horizon and C horizons. Deeper piezometers are often included, particularly if there are significant changes in grain size distribution in the lower soil profile. Soil studies usually include piezometers to 80 inches, the arbitrary lower depth of soil characterization in most parts of the country. Soil profile characteristics are available from the USDA Soil Conservation Service.

CONSTRUCTION OF PIEZOMETERS AND SHALLOW MONITORING WELLS: Monitoring wells and piezometers consist of four parts. Starting from the bottom and working up, these are (1) the well point, (2) the screen, (3) the riser, and (4) the well cap (Fig. 1). Other items that may be used in installation include (5) sealant to prevent water flowing along the sides of the pipe, (6) sand to ensure hydrologic contact and to filter out fines that move toward the well, (7) filter sock of geotextile to further filter out fine materials, and (8) concrete protection pads.

- The well point keeps soil from entering the well from the bottom. This may happen by sloughing during periods of high hydraulic head, particularly in sands and highly dispersive soils. Well points are bought separately if the wells are constructed of PVC pipe. One should drill holes or saw a slit in the bottom of a commercially manufactured well point to prevent the closed well point from holding water and giving false readings during drought.

- The screen allows water entry into the sides of the pipe. In shallow monitoring wells the screen extends from the bottom of the pipe to within 6 in. of the ground surface. In piezometers, the screen is the perforated end of the pipe, usually 6-12 in. in length.

  Commercially manufactured PVC well screen consists of finely slotted pipe. Screen with 0.010-in. width slots is adequate for most situations. In dispersive soils with high silt contents one should use 0.006-in. slots and a sand pack of 40-60 mesh silica sand.

  The slot size of the well screen should be determined relative to the grain size analysis. In granular non-cohesive strata that will fall in easily around the screen, filter packs are not necessary. The slot size should retain at least 90-99% of the filter pack (ASTM D-5092-90).

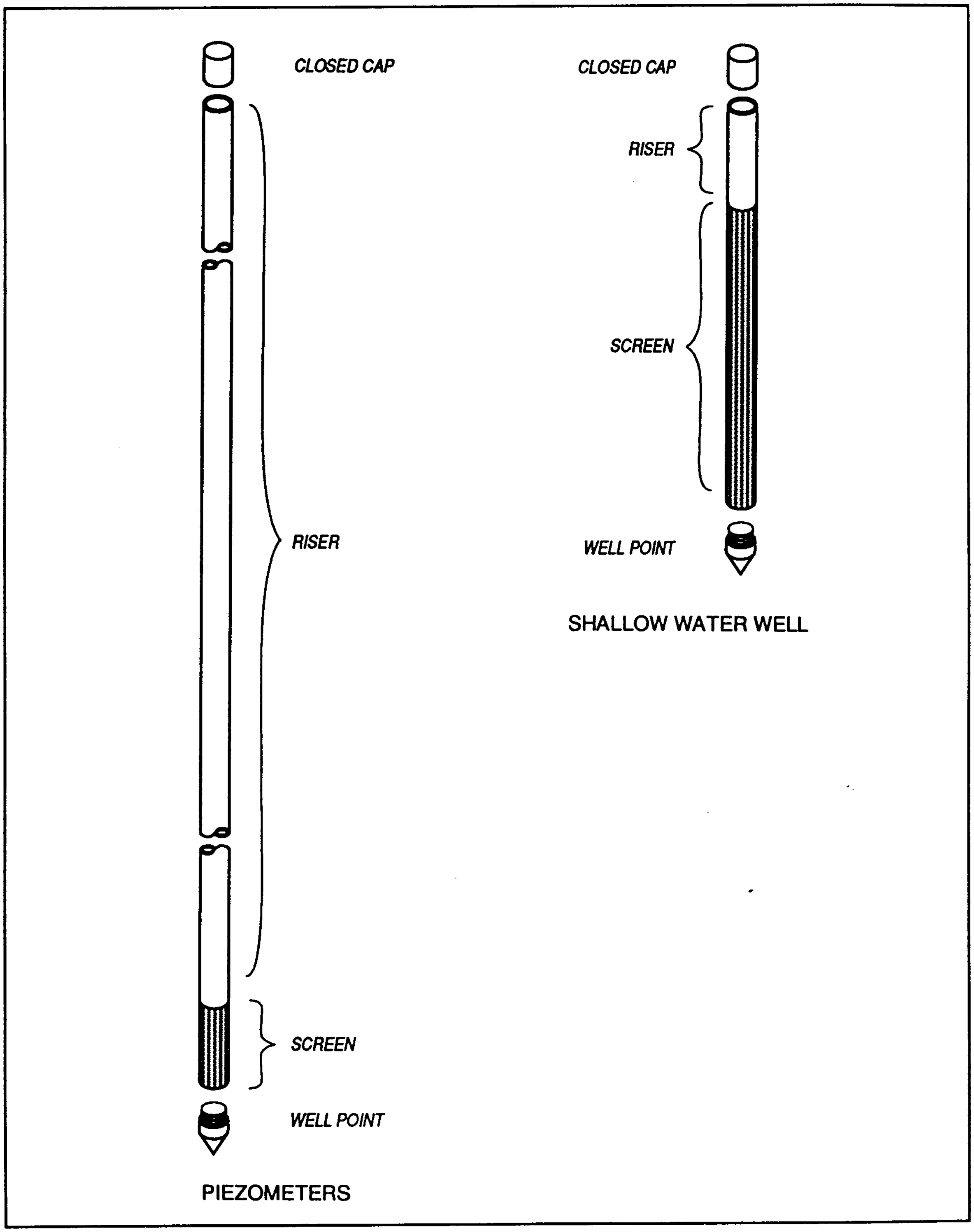

Figure 1. Parts of piezometers and shallow monitoring wells

- The riser is unslotted pipe that extends from the top of the screen through the ground surface and into the air to allow monitoring access. Riser of PVC is sold separately from the screen in 2 to 15 ft lengths. Sections of PVC riser may be screwed together to extend the riser to the length desired.

  The diameter of pipe used in piezometers and shallow monitoring wells depends on the purpose of the well and monitoring devices used. Pipes with an inside diameter (ID) of 1 in. or less are preferred. Small water samplers and automatic monitoring devices are available to be used in the small diameter pipes. If not, larger diameter pipe will be necessary, the size depending on method of sampling or monitoring.

  In shallow monitoring wells the riser should extend from 6 in. below the ground surface to the top of the pipe above ground. In piezometers the riser extends from the monitoring depth to the top of the pipe. Height above the ground surface depends on local needs such as visibility and access. Shallow pipes should not be extended more than a couple feet above the ground surface because of the great leverage that can be applied to the above-ground riser.

- The well cap is placed on top of the pipe to protect the well from contamination and rainfall. Well caps should fit tightly enough that animals cannot remove them and should be made of material that will not deteriorate with exposure to the elements. Threaded PVC caps meet these requirements in commercially bought wells.

  Well caps can be easily constructed from PVC pipe of larger inside diameter than the outside diameter of the piezometer. The larger ID pipe is cut to 6-in. lengths; one end of the 6-in. cylinder is then closed by gluing on an appropriately sized PVC cap (Fig. 2). Inverted plastic bottles or tin cans should not be used because of the ease with which they can be removed by animals or wind and because many such objects rust, degrade in sunlight, or break when frozen.

  Well caps should allow air pressure inside the pipe to equalize with that outside. Some PVC well caps are manufactured to allow air passage through a joint. Others should be modified so they cannot be threaded on tightly; this modification can be accomplished by closing the lower part of the threads with a bead of epoxy. If a vent hole is drilled in the side of the riser it should be too small for wasps to enter.

  After reading, well caps should not be secured so tightly that the shallow pipe must be pried and jostled to remove the cap. If surface water may overflow the tops of the pipes, caps should be secured so they will not be lost.

- Sealant is placed above the sand filter. This prevents water flow along the sides of the pipe from the ground surface and through channels leading to the pipe. If the well screen is below the water table at time of installation, the annular space above the sand is filled with bentonite to the top of the water table; grout is used to fill the annular space above the water table and to the soil surface. If the well screen is above the water table, at least 6 in. of bentonite is placed above the sand filter and grout is filled in above it.

  Bentonite is available in either powder or pellet form from well drilling companies. Pellets are easier to use in the field. Fine pellets can be dropped directly down the annular space above the sand filter. If this zone is already saturated with water, the pellets will absorb water in place, swell tight, and seal off the sand filter from the annular space above. If the bentonite pellets are

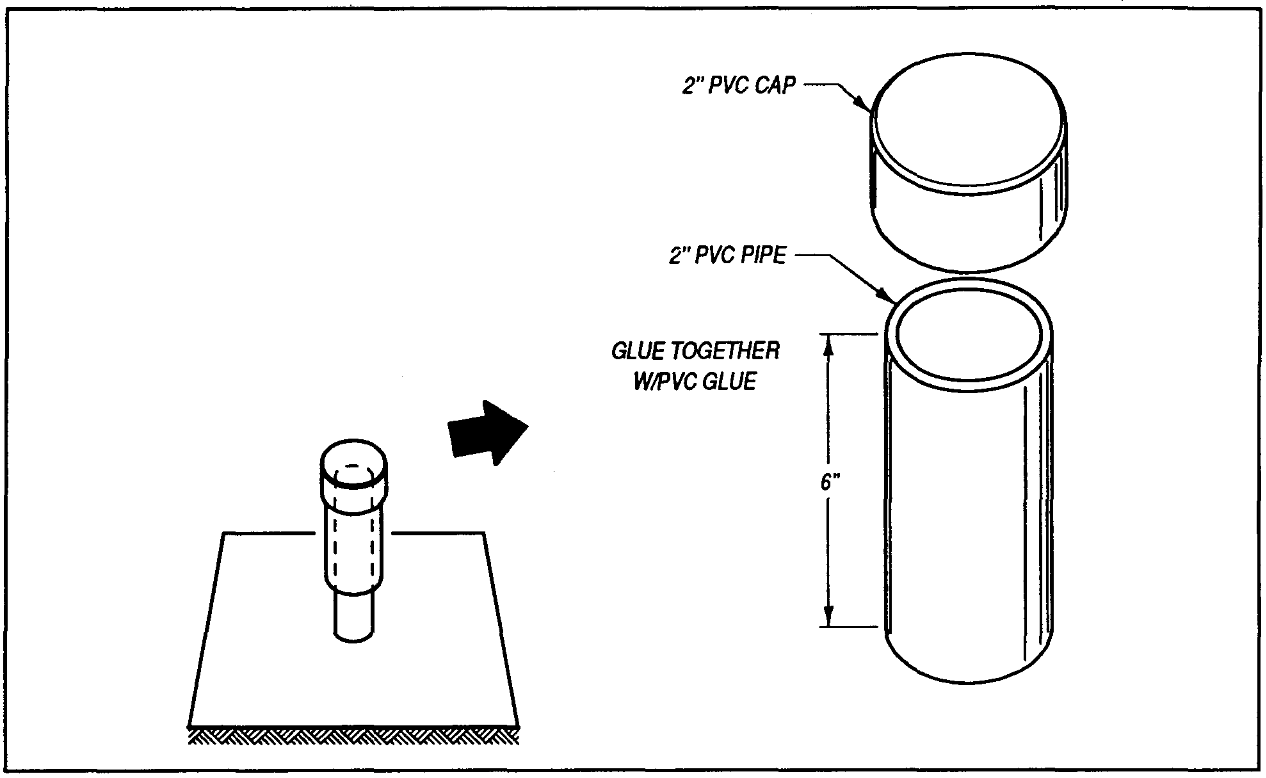

Figure 2. Homemade cap made of oversize PVC piping

dropped into a dry annular space it is necessary to drop water down, too, so the pellets can swell shut. The purpose of the bentonite collar is to prevent grout from flowing into the sand filter.

After the bentonite has been installed, grout is mixed and dropped down the remaining annular space up to the soil surface. The recipe for grout is 100 pounds of #2 Portland cement, 5 pounds of bentonite powder, and 7 gallons of water. The grout provides the primary protection from side flow down the riser because (1) it penetrates the surrounding soil matrix better than bentonite and (2) it does not crack during dry seasons.

- Sand is placed around the entry ports of the screen. Clean silica sand is commercially available from water-well supply houses in uniformly graded sizes. Sand that passes a 20 mesh screen and is retained by a 40 mesh screen (20-40 sand) can be successfully used with 0.010-in. well screen; finer sized 40-60 grade sand is appropriate for use with 0.006-in. screen. If available, the finer sand and screen should be used to pack instruments in dispersive soils with silt and fine silt loam textures.

  ASTM-5092-90 recommends that primary filter pack of known gradation be selected to have a 30% finer (d-30) grain size that is about 4 to 10 times greater than the 30% finer (d-30) grain size of the hydrologic unit being filtered. Use a number between four and six as the multiplier if the stratum is fine. This recommendation may not be achieved in clayey soils, in which case filter socks should be used.

- Filter socks are tubes of finely meshed fabric that can be slipped over the screened end of a well to filter out silt and clay particles that may be carried toward the pipe in flowing water. These

should be used in conjunction with sand packs in highly dispersive soils. Filter socks are available from engineering and water-well supply houses. Results of multi-year studies indicate that geotechnical fabric may clog up with microbial growth. In long term projects, filter socks must be monitored.

- Protective concrete pads are often poured around the pipe at the ground surface. They serve two purposes: (1) if large enough, concrete pads can prevent run-off water from channeling down the sides of the pipe, and (2) in many states they are required on all water wells to protect sources of drinking water from contamination.

  Accurate ground-water monitoring requires that instruments be isolated from incursion of surface run-off down the sides of the pipe. A large sloped concrete pad (3 or more feet in diameter) will usually prevent run-off from collecting around the pipe and preferentially running down it. However, water channels can develop underneath hastily installed concrete pads. Poorly constructed concrete pads will crack as the soil underneath settles or heaves with shrink/swell and freeze/thaw cycles. Installation of a tamped and wetted bentonite sleeve around the pipe and proper mounding of soil around the base of the riser at the ground surface will prevent side-flow more effectively than an improperly constructed concrete seal.

  Some states require that all monitoring wells be isolated from surface flow with a concrete pad. This regulation is intended to protect drinking water sources from pollutants in surface run-off. State regulations should be observed at all sites despite the inconvenience of transporting materials to remote locations. A copy of the state's water well regulations must be obtained and proper forms for each pipe must be filed. For shallow instruments that are many meters above aquifers or aquifer recharge zones it is recommended to consult with the appropriate state agency for an exemption. Most of the time common sense will prevail and such pads may be omitted from the design of very shallow wells.

INSTALLATION OF SHALLOW MONITORING WELLS AND PIEZOMETERS:

- Shallow Monitoring Wells. Installation method is for 2-ft deep monitoring wells.

  Uses: Shallow monitoring wells may be used to determine when the shallow free-water surface is within depths required by jurisdictional wetland definitions. These depths have historically varied from 0.5 to 1.5 ft and are shallower than the shallowest slowly permeable zone in most soils. Therefore, 2-ft deep monitoring wells are sufficient to detect water tables in most soils if the only information needed is whether a jurisdictional wetland is present. To know how much the water table fluctuates during the year at least one deeper piezometer should be installed next to the shallow monitoring well. Deeper wells with 3 or 4 foot screens require that horizons have similar permeabilities.

  Construction: Shallow monitoring wells used for wetland jurisdictional determinations should have 1.0-1.5 ft of well screen. Enough riser should be added above the screen to allow 0.5 ft of riser below ground and 0.5 to 1.0 ft of riser above ground. The above-ground portion of the riser should be kept to a minimum to protect the surface seal from disruption during accidental jostling. A vented well point should be added to the bottom of the screen and a well cap to the top of the riser.

  The total length of the instrument will be approximately 3 ft: 1.5 ft of screen, 0.5 ft of riser below ground, 0.5 ft of riser above ground, and 0.5 ft of well point and cap. The well should be

constructed of 1-in. ID PVC pipe with threaded joints unless water sampling or automatic monitoring devices require wider pipe.

Installation: A shallow monitoring well should be installed by (1) auguring a 2.5-ft deep hole in the ground with a 3-in. bucket auger, (2) placing 6 in. of silica sand in the bottom of the hole, (3) inserting the well into the hole with the vented well-point into but not through the sand, (4) pouring and tamping more of the same sand in the annular space around the screen -- this should be at least 6 in. below the ground surface, (5) pouring and wetting 2 in. of bentonite above the sand and (6) pouring grout to the ground surface. A final mound of grout prevents surface water from puddling around the pipe unless a concrete pad is required. Installation is illustrated in Figure 3.

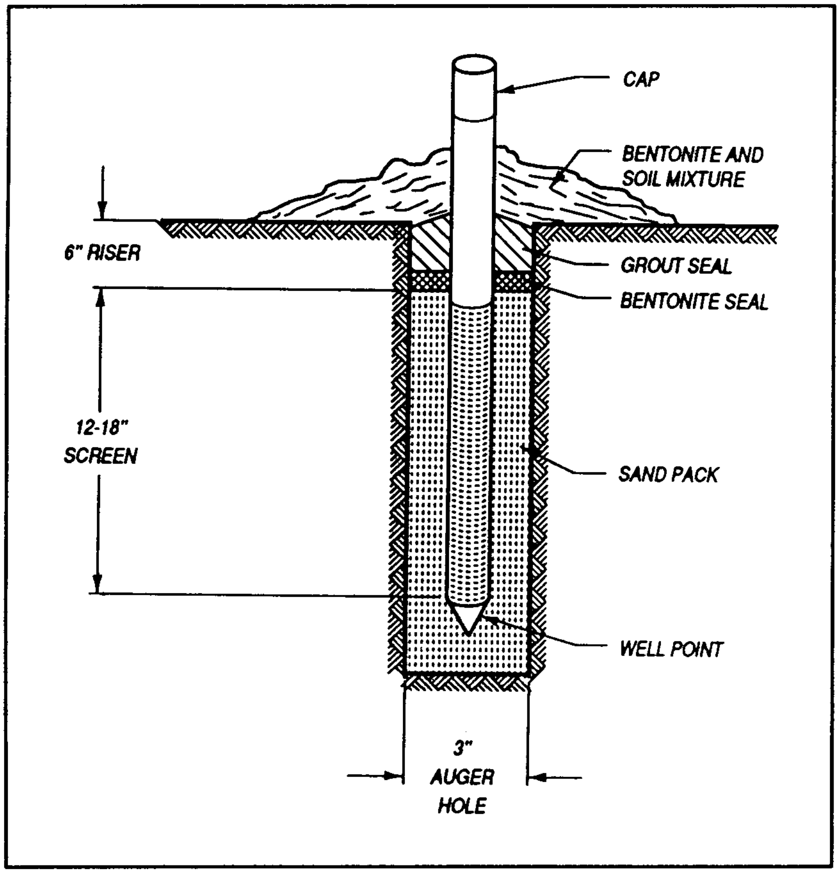

Figure 3. Shallow monitoring well

- Standard Piezometers. Installation method is for standard piezometers.

Uses: Standard piezometers are the preferred instrumentation for monitoring water tables. This method should be used whenever results may be published or litigated. Even in most jurisdictional studies involving shallow monitoring wells, a few standard piezometers should be installed around the project site to learn how deep the water table drops during the dry season.

Construction: Standard piezometers consist of 0.5-1.0 ft of screen, enough riser to extend above the ground, well cap, and vented well point. The total length of the piezometer will depend on the depth of the zone being monitored. Pipe diameter should be one inch unless sampling or monitoring instruments require wider pipe.

Installation: Installation of a standard piezometer entails (1) auguring a 3-in. diameter auger hole to a depth of 6 in. greater than the below-ground length of the piezometer; (2) dropping and tamping 6 in. of sand into the bottom of the augured hole; (3) inserting the well-point and pipe into the sand; (4) tamping sand around the length of the screen and 6 in. higher along the riser, (5a) if the sand filter is below the water table, pouring bentonite pellets into the annular space from the sand filter up to the water table, or (5b) if the sand filter is above the water table, pouring bentonite pellets at least 6 in. above the sand filter and wetting with water; and (6) pouring

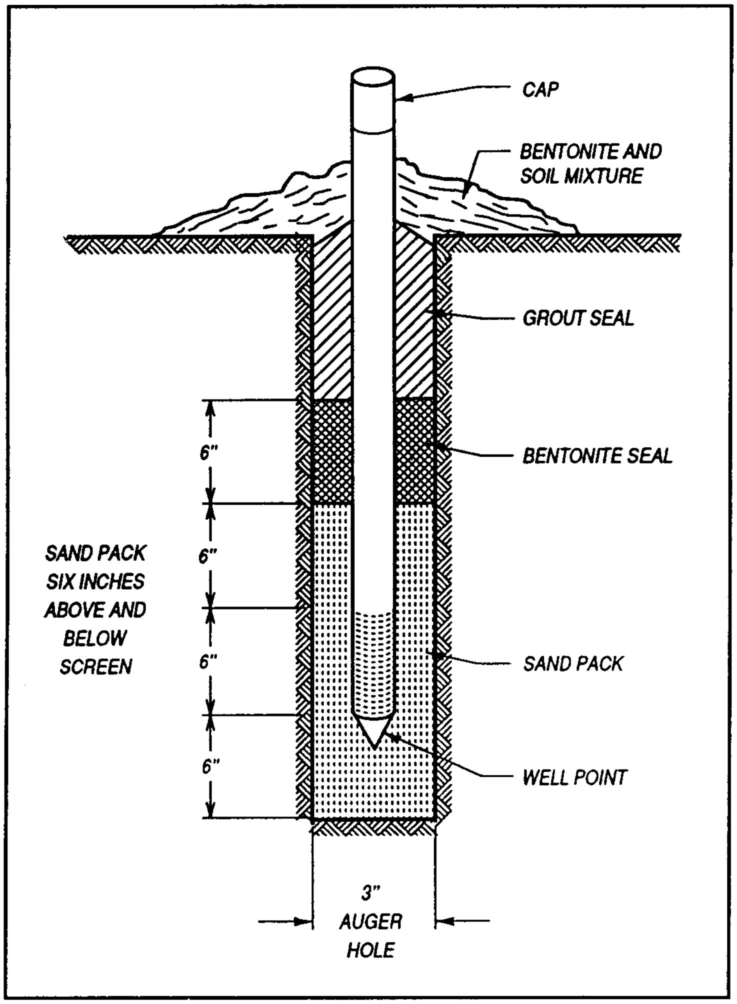

Figure 4. Standard piezometer

grout down the remaining annular space to the ground surface (Fig. 4).

The diameter of the auger hole should accommodate the pipe and an annular space of at least 1 in.; this will allow sufficient room to tamp in sand and pour bentonite without risking cavities in the sealant. The part of the hole that will be occupied by sand should be scarified if the soil is moist and smeared by the auger.

In deep sandy soils the bentonite and grout sleeves are not necessary because water flows through the entire soil matrix almost as quickly as down the sides of the pipe. The annular space around the riser is simply backfilled with sand that was removed during auguring. If the natural sand is fine enough to enter the slots of the piezometer, a sleeve of 20-40 grade sand should still be installed around the screen. If a less permeable layer is intercepted -- for instance, a spodic horizon -- that layer should be sealed with bentonite.

- Equipment Needed. Equipment needs will vary with depth and diameter of piezometers to be installed. The following is a list of equipment necessary for installation of shallow monitoring wells and standard piezometers to depth of 10 ft or shallower.

PVC well screen, riser, well points, and caps
bucket auger 2 in. wider than the OD of the pipe
auger extensions
pipe wrenches for auger extensions
tamping tool (0.5-in. thick lath 2 ft longer than the deepest well works well for wells up to 4 ft deep; 0.5-in. diameter metal pipe is necessary for deeper wells)
bentonite pellets
#2 Portland cement and bentonite powder (100/5 ratio)
bucket for mixing grout
water for grout and bentonite
silica sand
steel tape long enough to measure deepest hole
permanent marking pen to label pipes
concrete mix, water, wood forms, etc., for construction of concrete pads, if required

- Checking for Plugged Pipes. After the pipe has been installed it is necessary to assure that it is not plugged. For pipes installed above the water table fill the pipe with water and monitor rate of outflow; for pipes installed below the water table pump the pipes dry and monitor rate of inflow. If the screens are plugged one should re-install the pipes. This test should be performed every few months throughout the study.

READING WATER LEVELS: Numerous methods have been devised for reading water levels in shallow piezometers and wells. The simplest method is to mark a steel tape with a water-soluble marker and insert the tape to the bottom of the well. The only equipment needed with this method is the tape, marker, and a rag to wipe the tape dry after reading.

Other methods involve use of various devices at the end of a flexible tape. All suffer from the lesser accuracy obtained with a flexible tape rather than a rigid one. Most also suffer from inconvenience or complexity. Some of the variations are: (1) floating bobs on the end of a flexible tape (these must be calibrated to correct for length of the float and for displacement of water); (2) electric circuits that are completed when a junction makes contact with water; and (3) devices that click or splash when a flexible tape is dropped down the well (there is always uncertainty about the exact depth at which the noise was heard).

Water levels may also be monitored continuously with down-well transducers and remote recording devices. These cost around a thousand dollars per well but may be necessary for some study objectives. Automatic recording devices may pose special limitations on pipe diameter or construction, so the recording instrumentation should be investigated before pipe is bought. Because automatic devices may be re-used in many studies, cost estimates should be prorated over their expected life rather than assigned only to one study. If study objectives require frequent readings at remote sites an automatic recording device may be the only option available.

One method of reading water levels that should be avoided is insertion of a dowel stick down the pipe. Dowels displace enough water to give significantly false readings, particularly if the pipe has a narrow diameter and the dowel is inserted the entire length of the pipe. A steel tape also displaces water, but not enough to cause significant error.

When reading water levels height of the riser above the ground surface should be noted. Monitoring wells and piezometers may move as much as 3 in. in a season in clayey soils that undergo wet/dry or freeze/thaw cycles.

Frequency of reading will depend on study purposes. When determining consecutive days with water tables at a particular depth for wetland delineation purposes, daily readings may be necessary once the "growing season" starts. Daily and even hourly readings may be necessary to monitor tidally influenced wetlands. Longer term studies are usually adequately served with biweekly readings during most of the year and weekly readings during periods of water-table rise or draw-down. Long breaks between readings may cause ephemeral fluctuations due to intense storms or floods to be missed. If the study is important enough to be published or litigated, readings should be frequent and regular.

SOURCES OF ERROR: The following are significant sources of error with piezometers and monitoring wells: (1) side-flow down the riser, (2) plugged screens, (3) movement of pipes due to shrink/swell and freeze/thaw cycles, (4) water displacement during reading, (5) infrequent readings, (6) incorrect instrumentation, (7) pipes of too large a diameter, (8) faulty caps, and (9) vandalism.

- Side Flow. Erroneously high water heads can be recorded in piezometers and shallow monitoring wells if water is conducted to the screen faster than it normally would be through the soil. The most common source of this water is surface run-off channelled down the sides of the riser. It is critical that wells and piezometers fit snugly into the ground and that a collar of soil be mounded and tamped around the base of the pipe at the ground surface. This is the primary reason that the standard piezometer installation described here is preferred over simply driving the pipe into the ground; bentonite and grout seals are more secure than natural soil contacts along driven pipe.

  With piezometers, an additional source of error is subsurface water conducted to the pipe via cracks, root channels, or animal burrows. These problems will not be significant in all soils. When present, the only protection is an adequate sleeve of bentonite and grout around the riser.

  In montmorillonitic soils with high shrink-swell potential, one may never be able to eliminate cracks. In this case it may be necessary to auger soil samples from depth and determine water contents gravimetrically throughout the year. Such gravimetric determinations should certainly be made whenever false readings in piezometers are suspected.

- Plugged Screens. The slots or holes in screens may plug up, particularly in dispersive soils that are saturated for long periods of time. Algal growth can also plug up screens of instruments installed at biologically active depths. Plugged screens can give artificially dry readings during wet periods and artificially wet readings during dry periods. They will impede water flow so that fluctuating water tables can be missed even with frequent readings.

  Plugging of screens is most easily prevented by using an appropriately sized sand filter. One can check for such plugging by pumping wells dry on a regular basis and noting if they fill back up again.

  If shallow monitoring wells plug up, they should be re-installed. Deeper piezometers may be unplugged by pumping the wells dry several times and discarding the muddy water pumped out. If they continue to plug, they should be re-installed with 40-60 grade sand and 0.006-in. screen or with a filter sock.

- Movement of Pipes. Shallow pipes move much more than one would expect. Concrete collars can be lifted several inches above the ground in soils with clayey texture. This movement is caused by soil expansion during wetting or freezing. There is little one can do to prevent this, but one should monitor such movement by noting the height of the pipe out of the ground when reading water table depths.

  Pipes that move a lot and experience inundation as well probably no longer fit snugly in the ground and therefore experience side-flow down the riser. Gravimetric water contents should be checked whenever one suspects false readings due to side flow. If these problems persist, piezometers should be re-installed.

- Water Displacement. As mentioned previously, water levels in wells should not be read by inserting a dowel stick down the pipe. The dowel will displace its volume in water and thereby give an artificially high reading. A marked steel tape should be used instead.

- Infrequent Readings. A common source of error in many long-term studies is missed or postponed readings. Before the study is started one should arrange for sufficient help to make readings on schedule and frequently enough to answer study questions. It is all too easy for

professionals with many other responsibilities to delay a trip to the field because of intruding obligations. Yet, gaps in a data set will call an entire study into question. If budgets allow, automatic recorders may solve the problem.

- Incorrect Instrumentation. Piezometers are preferable to shallow monitoring wells for most questions more complicated than simple presence or absence of water tables in the rooting zone. Water levels in monitoring wells are composites of the hydrologic head at all depths intercepted by the well screen. Consequently, perched water tables will usually be misinterpreted if monitoring wells penetrate the drier substratum beneath.

  Readings from improperly placed piezometers can also be misinterpreted. Piezometers should not be placed at uniform and arbitrary depths without reference to soil horizon differences. Piezometers placed at arbitrary depths are likely to straddle horizon boundaries or entirely miss highly permeable horizons with significant subsurface flow.

- Large-Diameter Wells. Piezometers and wells should be as narrow as practical. The wider the pipe, the greater the volume of water that has to move in and out of it in response to changes in hydraulic head. Consequently, a large-volume monitoring well will respond more sluggishly than a small-volume well. This is more critical in soils with low permeability and for studies that require monitoring several times a week or shortly after major precipitation events.

  Most wells can be successfully constructed from 1 or 1.25 in. pipe. Use of 4 or 6 in. pipe should be avoided unless study conditions require the larger pipe. An excessively large annular space should also be avoided, for the same reasons.

- Faulty Caps. Commercially manufactured caps often fit too tightly on PVC riser, necessitating excessive force to remove them. The resultant jostling can disrupt the seal between the pipe and the sealant, allowing water flow along the side of the pipe. To avoid this, threaded caps -- if used at all -- should be screwed on the pipe loosely. Avoid caps made of materials that deteriorate and break in sunlight or frost, can be nudged off by animals, or blown off in the wind. Most such problems can be alleviated by use of home-made caps constructed as described in Figure 2.

- Vandalism. Often vandalism cannot be avoided. Three approaches to the problem are (1) to hide the wells, (2) to shield them, and (3) to post them and request they not be disturbed. Simple signs stating "Ground-water pipes: please do not disturb" have been used successfully. In some communities it may be better to hide the pipes. Padlocks may keep out the curious. A second and larger pipe surrounding the above-ground portion of the monitoring well may offer protection against gunshot. Still, pipes probably cannot be protected from the malicious. Extra equipment should be bought at the beginning of a project so that vandalized wells can be replaced.

INTERPRETING RESULTS: As mentioned previously, data from shallow monitoring wells are ambiguous unless the well is very shallow (2 ft or less), or the soil is highly permeable or unstratified. A 4-ft deep well that traverses a profile of A-E-Bt-C is likely to miss the slightly perched water table that rests on top of the Bt and in the E. The most permeable horizon contributes the most water to a water well. If the bottom of the well intercepts an unsaturated horizon of higher permeability, then water can actually be wicked away from the well.

Piezometric data can also be confusing unless one is familiar with principles of water flow. If water is static in unstratified soil, water levels in all piezometers should be the same (Fig. 5). However, if

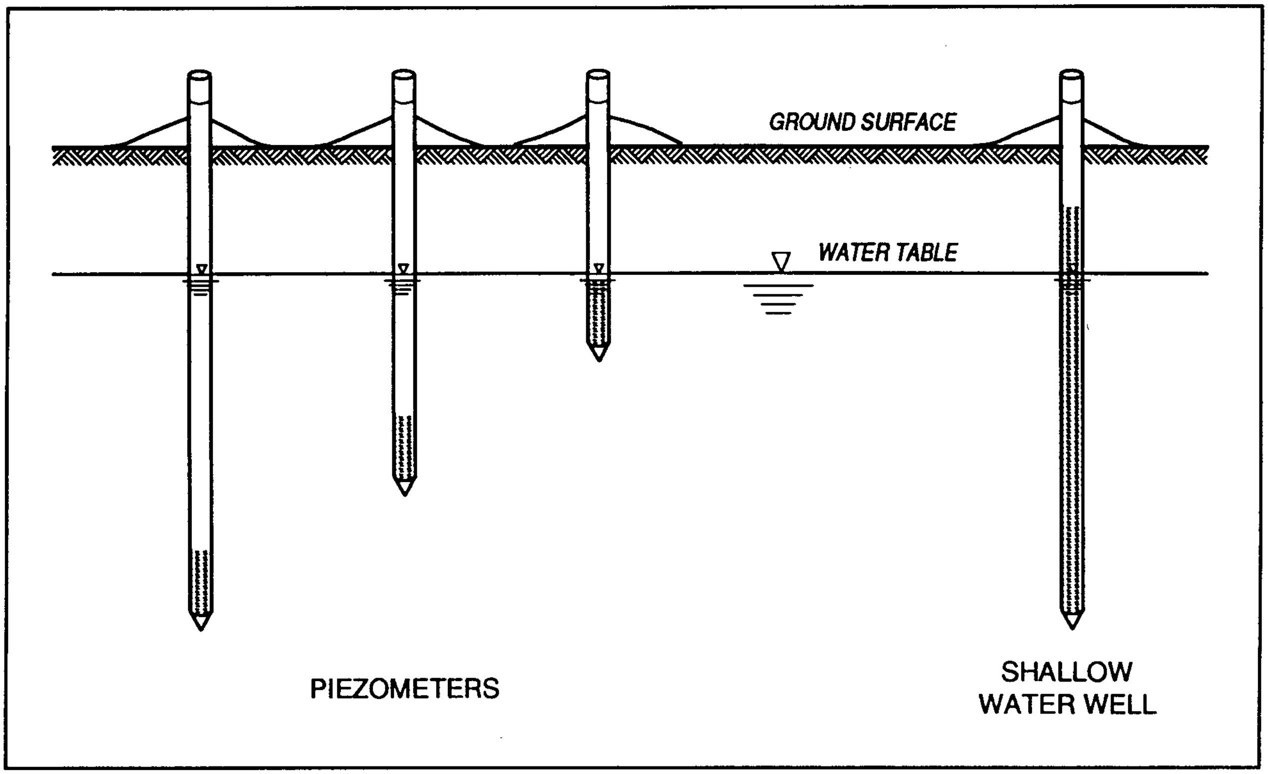

Figure 5. Instruments in unstratified materials with static water-table

differentially permeable strata are present or if water is moving up or down the soil profile, then piezometers will record different water levels at different depths.

A perched water table can be inferred from higher piezometric levels in the A or E horizon than the C (Fig. 6). For soils of uniform permeability, downward water movement (aquifer recharge) can be inferred from higher piezometric levels high in the soil and lower piezometric levels low in the soil (Fig. 7). Upward water movement (aquifer discharge) can be inferred from lower levels high in the soil and higher levels low in the soil (Fig. 8). Water moves from a zone of high pressure to a zone of low pressure, even against gravity, if the pressures are great enough. Proper interpretation of data requires some knowledge of soil horizonation and likely water sources.

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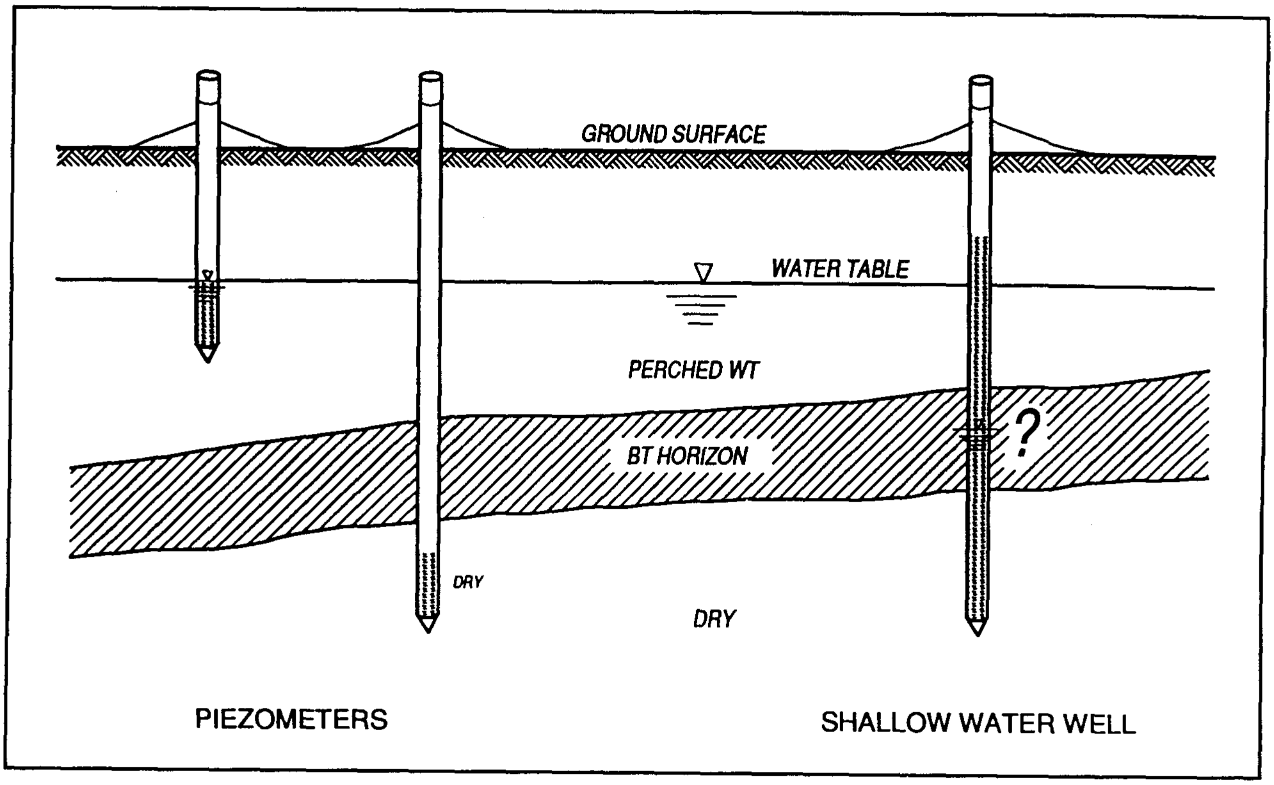

Figure 6. Monitoring instruments in stratified materials with perched water-table

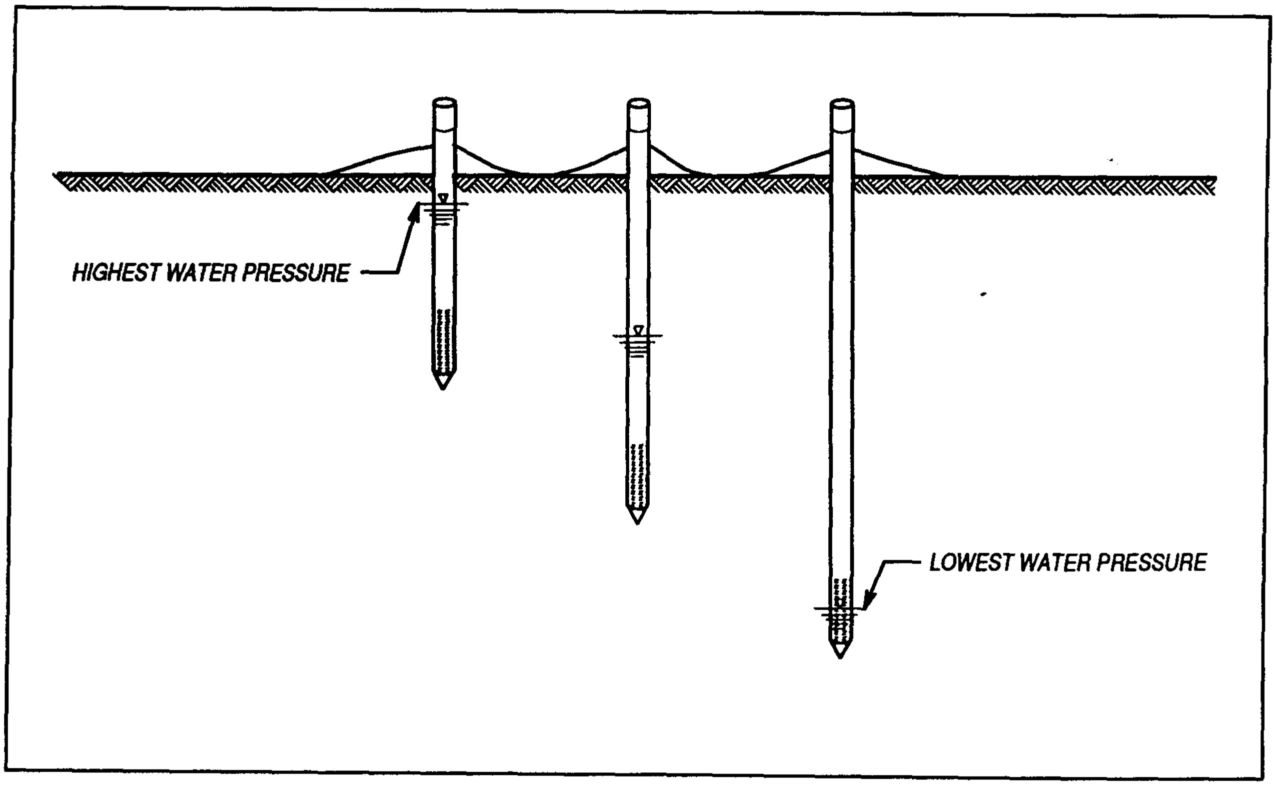

Figure 7. Recharge system with water flowing downward

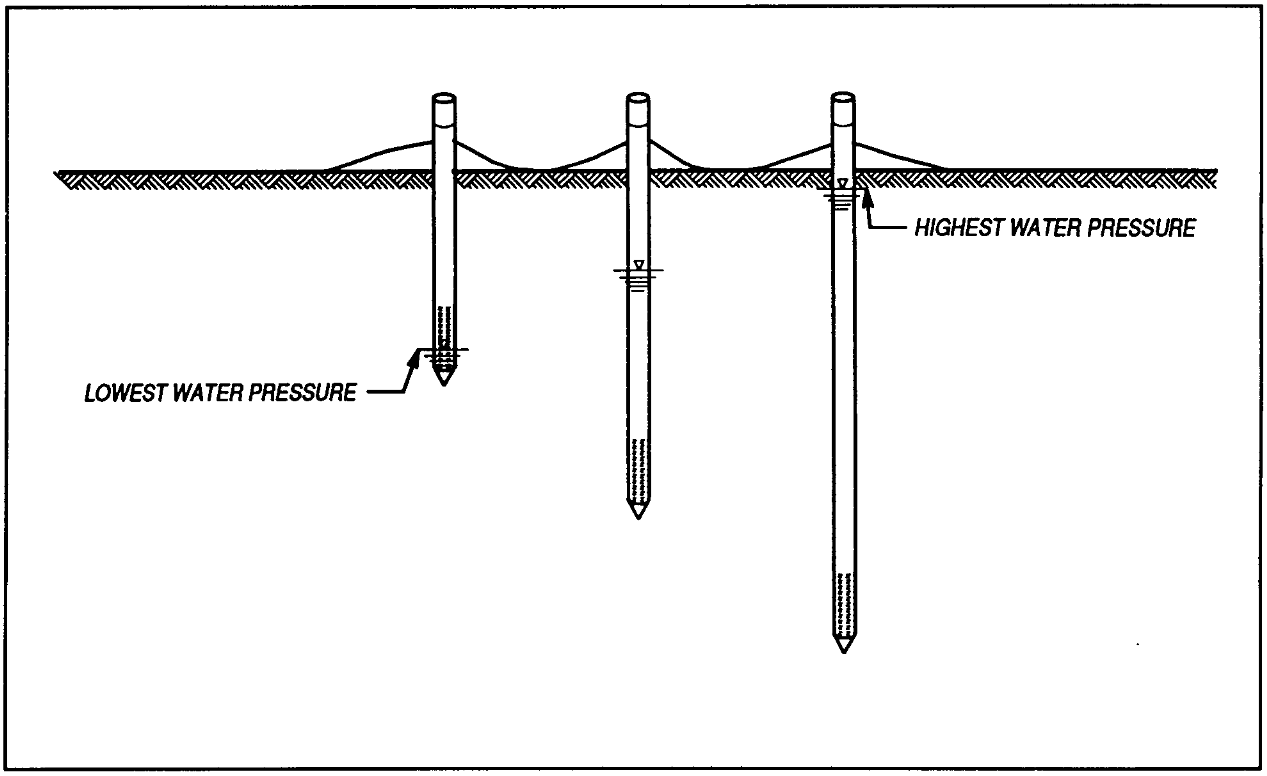

Figure 8. Discharge system with water flowing upward

US Environmental Protection Agency. 1975. Manual of Water Well Construction Practices, Office of Water Supply, EPA-570/9-75-001.

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